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TITANIUM

Encouraging results have been reported recently on the North American Rockwell program to produce diffusion-bonded laminated structures for use in place of forgings.[1] North American has proceeded to the fabrication and testing of parts from 0.125-inch-thick Ti-6Al-6V-2Sn alloy that contain "pockets". Tensile, fracture-toughness, fatigue, and unstressed thermal-exposure tests of these structures indicate that they have generally higher and more consistent properties than do equivalent forgings. Compared with the forged fittings, laminated parts exhibited a 33 percent longer fatigue life and a 40 percent greater short-transverse fracture toughness.

Laminated titanium parts with large section thicknesses, made by diffusion bonding, are expected to offer design and lead-time advantages that will make them economically feasible.

As a result of developmental effort on the supersonic transport and other programs, considerable data are becoming available on the properties of the Ti-8Al-1Mo-1V alloy.

Curtiss-Wright has examined the general welding characteristics of Ti-8Al-1Mo-1V alloy for use in the fabrication of turbine-engine components.[2] Conclusions reached verify all of the accepted criteria for successful welding of titanium alloys. For this application, particular attention must be given to design allowances made for the greater bead width and shrinkage encountered with titanium. Shrinkage generally decreases with increasing travel speeds at constant heat input-per-unit weld length. Distortion decreases as thickness increases in sheet-metal weldments in the thickness range from 0.020 to 0.060 inch. Shrinkage and distortion are considerably less for electron-beam welding than for inert-gas tungsten-arc welding. Hand welding was not considered applicable to the welding of engine components. The short weld length, high welding speed, and penetration all require that a high degree of automatic control be placed on all welding parameters.

A further study made at Curtiss-Wright was designed to evaluate the extent of mechanical instability of weld joints in Ti-8Al-1Mo-1V alloy sheet.[3] Specimens of the base metal plus electron-beam and inert-gas tungsten-arc welds were exposed in an air environment as follows:

Temperature, F	Load, ksi	Time, hours
600	35	150
750	25	150
900	15	150

After exposure, tensile tests were conducted at room temperature, and the results of these tests are shown in Figure 1. Some of the results of the study were:

(1) Strengths were not greatly changed by these exposures

(2) Inert-gas tungsten-arc welds that failed in the weld showed a loss in ductility but electron-beam welded specimens failed in the base metal

(3) The microstructure of the weld metals did not change during exposure

(4) The electron-beam welds had a much smaller grain size, which could explain differences in mechanical properties and failure mode.

A test program was conducted at LTV Aerospace to evaluate the fatigue behavior of a fusion-welded structural assembly to supplement information available on riveted and spot-welded structures.[4] The tests were performed on box beams having tension covers featuring typical skin-stringer welded structures. The alloy used was Ti-8Al-1Mo-1V in the duplex-annealed condition. Both constant-amplitude and spectrum-fatigue tests were performed at room temperature and 550 F. Spectrum tests were conducted under conditions that simulated the environment of the supersonic transport.

The results of these tests, compared with those on spot-welded and riveted specimens consisting of box-beam structures 120 inches long, 22.5 inches wide, and 8.0 inches deep, are shown in Table 1. In general, the cracks developed in welded structures were randomly located, but always began in the weld. Fusion-welded specimens had longer fatigue lives than did either the spot-welded or riveted specimens. Cracking in the welded specimens was confined to longitudinal welds and the fatigue damage sites did not relate to flaw sites located by X-ray inspection.

Howmet engineers have demonstrated the feasibility of repairing titanium investment castings by welding.[5] Ti-6Al-4V alloy castings can be repaired by using the inert-gas tungsten-arc process

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FIGURE 1. ROOM-TEMPERATURE MECHANICAL PROPERTIES OF Ti-8Al-1Mo-1V AFTER LOAD EXPOSURE[3]

TABLE 1. SUMMARY OF TEST RESULTS OF FUSION-WELDED, SPOT-WELDED, and RIVETED SPECIMENS[4]

	Constant Amplitude, Room Temperature, S_{max} = 25 ksi, S_{min} = 12.5 ksi			Constant Amplitude, 550 F S_{max} = 41.25 ksi, S_{min} = 35 ksi			Spectrum, Room Temperature and 550 F, S_{1gd} = 25 ksi					
	Fusion Welded	Spot Welded	Riveted	Fusion Welded	Spot Welded	Riveted	Fusion Welded		Spot Welded		Riveted	
Predicted Life, linear cumulative damage theory	90,000 cyc	13,000 cyc	36,000 cyc	500,000 cyc	75,000 cyc	90,000 cyc	29,000 flts	29,000 flts	3,100 flts	3,100 flts	7,400 flts	7,400 flts
Time to l_c = 0.03 in.	27,233 cyc[a]	—	8,450 cyc	—	49,000 cyc	41,700 cyc	5,250 flts	2,750 flts[e]	(f)	775 flts[b]	5,600 flts	9,500 flts
Time to l_c = 0.50 in.	33,250 cyc	25,000 cyc	24,000 cyc	—	80,750 cyc	99,000 cyc	(d)	2,750 flts[e]	—	1,000 flts[b]	6,815 flts	(d)
Duration of Test	52,877 cyc	33,345 cyc	48,301 cyc	301,364 cyc[c]	159,955 cyc	154,047 cyc	12,500 flts	12,250 flts	—	2,500 flts	12,500 flts	12,500 flts

Notation Used:
   l_c - crack length, inches; S_{max} - highest algebraic value of stress in the stress cycle with tensile stress positive; S_{min} - lowest algebraic value of stress in the stress cycle with tensile stress positive; S_{1gd} - stress level at take off design gross weight, one g.

(a) Crack had attained a length of 0.22 inch prior to detection.
(b) Based on extrapolation of test data.
(c) Specimen had sustained no damage at this point.
(d) No cracks attained a length of 0.50 inch.
(e) Crack appeared suddenly between 2500 and 2750 flights.
(f) Specimen suffered an instability failure after completion of 1250 flights.

with either base metal or 65A filler rod. Ti-5Al-
2.5Sn castings are repaired with 65A filler rod.
The technique is limited to relatively shallow
flaws. Deep, sharp notches prevent complete notch-
base penetration.

Fabricators interested in the spot welding of
titanium should be aided by the data given in
Figures 2 and 3.[6] They were presented at a re-
cent meeting of the SAE in Los Angeles.

Concern with the effect of hydrogen on welds
in titanium has prompted the publication by the
Defense Metals Information Center of the Technical
Note "Effects of Hydrogen in Titanium Welds", dated
April 10, 1967. This Technical Note is available
to qualified requesters from DMIC.

STEEL

McDonnell Douglas engineers have reported on
the susceptibility of the HP 9Ni-4Co alloys to
stress-corrosion cracking.[7] Microstructural vari-
ations, nonporous surface films, and high surface
compressive stresses were found to be the most im-
portant factors affecting stress-corrosion resis-
tance. Fusion welding of the HP 9Ni-4Co-0.30C alloy
by the inert-gas tungsten-arc process drastically
lowered stress-corrosion resistance of weldments
heat treated to 220,'240 ksi ultimate strength.
Failures were in the heat-affected zone. Stress
relief in the 950 to 1050 F temperature range gave
some improvement, but it was necessary to shot peen
to restore stress-corrosion-cracking resistance.
No work was reported on the HP 9Ni-4Co-0.45 C alloy.

A literature review on the 3.5 and 9 nickel
steels has recently become available that summarizes
the effect of welding-process variables on impact
and tensile properties.[8] Surface preparations, pre-
heating, post heating, stress relief, and shielding-
atmosphere effects, along with welding costs and
weld quality, also are covered.

In continuing studies to develop a weldable
HY 180/210 steel for the Navy, the U. S. Steel Re-
search Laboratory has examined the HP 9Ni-4Co-0.25C
steel.[9] The results indicate that, with proper
heat treatment, yield strengths in the range of
175 to 184 ksi can be obtained. Charpy V-notch
properties at 0 F were around 30 ft-lb for 4-inch-
thick plate and up to about 47 ft-lb for 0.5 inch
plate. The ductile-to-brittle transition tempera-
ture ranged from -200 F for 1-inch plate to greater
than 150 F for 4-inch plate. This steel was not
rated high for use where thick plate must be welded.

Other studies in progress under the same Navy
contract, by U. S. Steel, are concerned with base
metal, filler metal, and processing development of
both HY-110 and HY 130/150 weldments.[10,11]

MISCELLANEOUS

Solar has initiated a program for the Air
Force on the electron-beam welding of thick sec-
tions.[12] The general objective is to find causes
of defects and develop procedures for their elimina-
tion. Nickel-base, aluminum, titanium alloys,
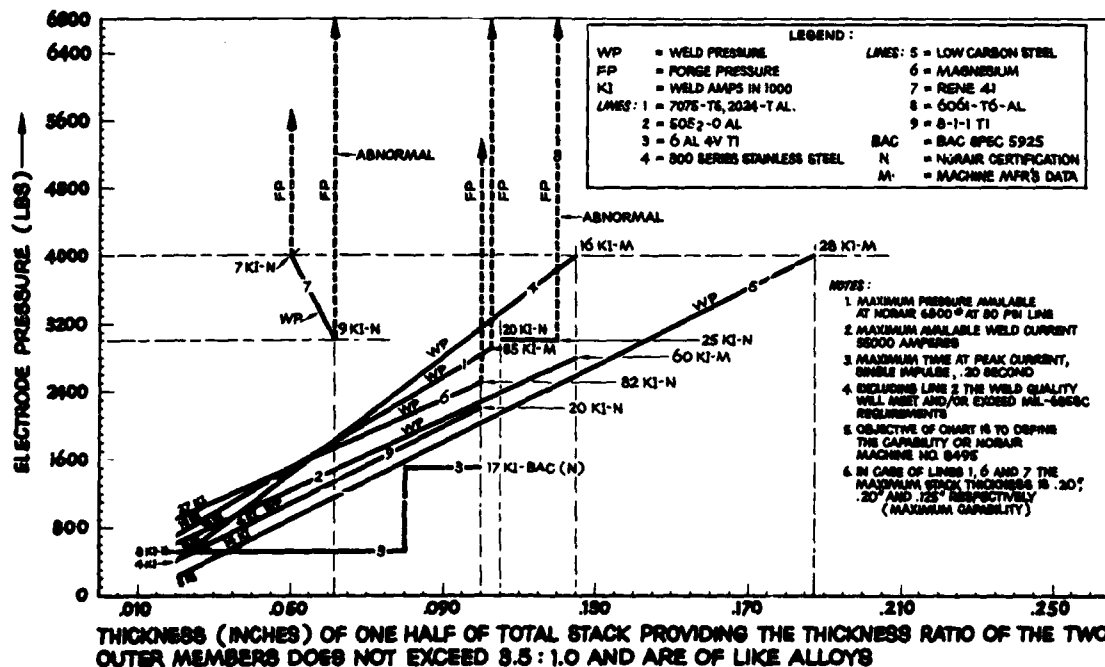and steels are included in the study.

FIGURE 2. "GUIDE" CURRENT AND PRESSURE REQUIREMENTS TO RESISTANCE SPOT WELD, NOTED ALLOYS, AND GAUGES

NOMINAL GAGE IN.	ELECTRODE DYNAMIC FORCE LBS.			TIME CYCLES		IMPULSES	SPOT SHEAR LBS.	WELD CURRENT (HEAT MINUS HEAT LOSS)
	WELD	FORGE	RADIUS IN.	WELD	COOL			
.020	400	0	4	4	.5	1	900	
.030	400					1	1100	
.040	450		4			1	2100	
.050	450		8			2	2800	
.060	650					4	3600	(a)
.070	750						4500	
.080	875		8				5300	
.090	1000		10				6100	
.110	1150						7000	
.125	1500	0 FORGE BECOMES NECESSARY	10	4	.5	4	3400	

(a) Expressed as $H = I^2 RtK$,

where

    H is the total heat generated
    I is the current in "amperes flowing through the weld"
    R is the resistance in ohms, total
    t is the time in seconds
    K is the heat lost by conduction into the surrounding sheets and into the electrodes.

The number of amperes is of little significance, since amperes, amperage density, time, and resistance are "complementary to each other" and because of the extreme difficulty in defining the H, K, and R value. They are seldom, if ever, known; therefore, current in terms of numbers tells only very little in terms of the net resulting weld.

FIGURE 3. RESISTANCE SPOT WELDING-TITANIUM ALLOYS, APPLICABLE WELDING SCHEDULES[6]

Progress on the utilization of explosives for the spot welding of several metals has been reported by Aerojet-General.[13] Alloys successfully welded were AISI Type 347 and 17-7PH stainless steels, Ti-6Al-4V, Ti-8Al-1Mo-1V titanium, and 2024-O aluminum. The thickness of specimens was 0.063 inch. A spark-gap initiator and a wad of Permagum integrated in the explosive charge provided a self-contained welding package without the need for any additional energy-transmission medium. A special hold-down technique permitted production of satisfactory welds while protecting previously made welds. High-speed photography in conjunction with flash X-ray studies showed that the metal motion must be in diverging radial paths in order to form successful welds.

A final report on the development of fluxless brazing methods for fabricating structures made from aluminum thin-wall tubing and foil has been issued by Avco.[14] The overall objectives of this program were to establish the limitations of fluxless brazing and diffusion bonding of composite structures, and to demonstrate the optimum processes required for small complex structures.

The primary accomplishments as recorded in the report are that aluminum alloys suitable for brazing are not readily available as foil and that commercial braze filler metals are available only as powder, wire, or sheet. The study concluded that aluminum-alloy foils could be produced by re-rolling and that braze alloy available as sheet could be reduced to foil for experimental purposes by chemical milling.

Salient achievements reviewed in the report are briefly summarized as follows:

(1) Aluminum honeycomb cores with metallic nodes suitable for brazing methods were surveyed. Satisfactory ultrasonic-welded aluminum honeycomb core blankets were produced.

(2) Alkaline- and acid-base chemical cleaning systems were reviewed, and three were proven to be satisfactory for prebrazing surface conditioning.

(3) Relative atmospheric oxide-formation rates for several base-metal aluminum alloys were determined.

(4) Capillary-rise power and bridging characteristics of two commercial braze filler metals on 6061 aluminum were demonstrated.

(5) Fluxless brazing with commercially available materials was demonstrated as being suitable for structural, cryogenic, and elevated-temperature environments for complex aerospace composites.

(6) A low-pressure diffusion-bonding process with commercially available materials was successfully developed and demonstrated for joints that can be positively held in intimate contact during joining. However, the process was limited in multijoint lightweight-composite applications, and, as such, was not a suitable alternative method for the fluxless brazing process.

The feasibility of developing new brazing filler metals with lower wetting and flow temperatures than the commercially available materials was established. Experimental aluminum-base complex systems exhibited minimum effective wetting temperatures up to 50 F lower than the available systems, with acceptable joint strengths.

Of the systems investigated, the AlSi + copper ternary offered the best combination of strength versus wetting temperature. The AlSi + magnesium system offered the lowest wetting temperature. The AlSi + indium system, based on its microstructure, is a potential candidate for corrosive-environment applications, although in this area the AlSi + magnesium ternary, based on known data, also should exhibit good corrosion resistance.

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